RICHARDS

Influences of Rock Character, Relief & Climate on Spacing of Streams

Science

A. B.

1914

INFLUENCES OF ROCK CHARACTER, RELIEF AND CLIMATE ON SPACING OF STREAMS

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF ARTS

IN

SCIENCE

COLLEGE OF LIBERAL ARTS AND SCIENCES

UNIVERSITY OF ILLINOIS

1914

UNIVERSITY OF ILLINOIS

June 6 1914

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Helen Marie Richards

ENTITLED Influence of Rock Character, Relief and Climate on Spacing of Streams

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Arts in Science

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APPROVED: June 5 1914

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Geology

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THE INFLUENCE OF ROCK CHARACTER, RELIEF AND CLIMATE ON SPACING OF STREAMS.

I. INTRODUCTION.

1. The Problem.

The purpose of this discussion is to demonstrate what normal factors are instrumental in determining the spacing of streams, and especially to show how, and to what relative degrees the three prime factors, rock character, relief and climate are effective.

Up to the present time this field, the investigation of stream spacing along lines of normal stream action, has either warded off everyone or enticed no one, for in an extensive survey of geological literature I have been unable to find any article devoted exclusively to a thorough discussion of the problem, and have found but a hint here and there in connection with allied problems. Nearly all the literature on the subject is devoted to a consideration of fracture systems as prime determinants of spacing, quite disregarding the possibility and even probability that more or less definite spacing of streams may be a normal feature entirely irrespective of structure. The structural side of the question, however, has been brought out by W.H. Hobbes in a discussion on "Repeating Patterns in Relief and in Structure of Land Forms",(1) by A. Daubree (2) and by Iddings.(3)

Quite the opposite extreme is taken by N.S. Shaler in an article entitled, "Spacing of Rivers with Reference to Hypothesis

(1) Hobbes, W.H. -Bul. Geol. Soc.Am:-Vol 22: No.4:pg. 717-1911
(2) Daubree,A.,"Geologie Experimentale". Paris 1879.
(3) Iddings "A Tracture Valley System". Jour. Geol. Vol. 12. pg. 94-105:1904

of Base Leveling",[4] in which he says that water courses in nearly all regions are somewhat regularly spaced, and intervals between streams of like size are approximately the same even when character of rocks and amount of rainfall are somewhat varied. Too, he mentions that in regions which have been exposed to erosion for some time the phenomena of equal spacing and equal slopes are very marked. This led him to conclude that equal distribution of streams is brought about in some way by stream action. He even goes so far as to state that this tendency to approach uniformity of intervals and lateral slopes will eventually tend to produce likeness in heights even where the original surface was uneven. He says for instance, that the similarity in heights in the Allegheny plateau is not necessarily due to former peneplaination, but would, in natural course, be evolved by normal stream action.

J. E. Spurr in an article entitled "Relation of Faults to Topography", [5] says that folds and faults of first and second order can not be successfully combated by erosion and thus determine stream courses and stream spacing, but those of third order are generally overcome by erosion. The truth of Spurr's conclusions seems evident for clear examples of structural control were found in the course of our investigation (Plate VII and VIII) yet such cases were ruled out as far as possible because exhibiting special, not general conditions. Another who has given a few scattered hints on this subject is Marius R. Campbell, in his paper entitled "Drainage Modifications and their Interpretations." [6] He admits that Hobbes, Iddings, Daubree and others can point out special areas

(4) Shaler, N.S., Bul. Geol. Soc. Am. vol.10 pg. 263-276: 1899
(5) Spurr, J.E. - Science - vol. 17 New Series. pg. 792: yr.1903.
(6) Campbell. Marius, R. Jour. Geol. vol. IV. pg. 567-81,657-678: 1896.

where the spacing is due to structuralcontrol, but he also says that such complicated geological structure, as that on which they base their arguments and conclusions is limited in extent as compared to the great mass, and thus the idea of structural control over stream spacing does not deserve the prominence commonly attached to it. Penck, on "Verschiebungen der Wasserscheiden". (Shifting of watersheds)(7) says that the height of a water shed is determined by the spacing and angle of slope, which in turn, are conditioned by climate and rock character. He thus makes spacing a function of rock character, relief, and climate. This is the foundation upon which the present investigation is based and which it shall now proceed to verify.

2. Scope of Present Investigation.

In order to arrive at any conclusions which, in view of sound statistical principles, could be considered at all authentic it has been necessary to take data from a great variety of localities, in order to insure all possible combinations of relief, climate and rock character. In accordance with this, data have been taken from various parts of the United States, Alaska, France and Germany. Too, in order to restrict our variables to the above three, it has been necessary to take all data from regions of practically the same stage of erosion. Any one of the three stages, youth, maturity or old age could be used to give uniformity, but in case of youth the drainage system is still in its making and thus poorly integrated. In old age, on the other hand, there is an over-development; the angles of slope having reached their maximum value in maturity are now decreasing, tending to produce a gradual subsidence of divides and a general pene-plaination of the region. It is evident that

(7) Penck, Albrecht.-"Morphologie der Erdoberfläche". pg.360-373.

neither youth nor old age are suitable stages for our purpose, but maturity, which is the time when maximum slopes are just reached and the system completely integrated, is the stage which denotes fullest development and is thus most suitable for an investigation of the factors producing this perfected system.

3. Methods of Procedure.

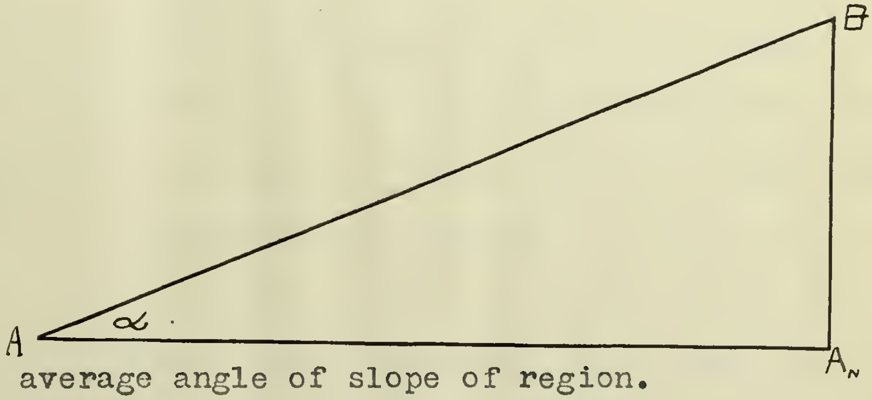
The impossibility of gathering data in the field when so great a range of localities was involved forced the taking of data from geological maps and folios. Thus for each of several different formations a considerable number of maps of mature topography were chosen to give a basis for determining the effects of rock character on spacing. Also, maps from every available quarter of the world werechosen in order that the effect of climate on spacing might be discovered. With these bases for selection fixed the method of procedure was as follows: First, tracings of the stream patterns of the most uniformly mature topography of each section where taken, (Plates I to X) and on each the following items were noted for reference: Name of section, scale of miles, contour internal, formation, average relief, average angle of side slopes and spacing. The relief was arrived at by taking the average of about a dozen of the highest points less a similar average for the lowest points. The spacing was taken directly from the tracings by running lines across them in every conceivable direction, counting the number of streams crossed in the total combined distance and then from this, calculate the average spacing. Taking the average angle of slope involved the question of the advisability of taking a plain average or a weighted average with the decision in favor of the later as showing more accurately the average slope, since by this method

a short steep scarp slope would not receive as much weight in determining the average angle of the whole region as a longer slope of equal steepness.

The above weighted average was arrived at as follows: wherever in the section being studied the slopes seemed fairly uniform a straight edge of paper was applied to a slope and the length of the slope (AA_1) having a relief of a_1 feet was marked off (see diagram). In measuring a second slope, point A_1 was applied to bottom of the slope and length ($A_1\ A_2$) of second slope measured, thus at the same time adding it graphically to AA_1. After continuing this process a great number of times say n_1 each time measuring a different slope, we have a distance of ($A\ A_n$) miles with combined relief of ($a_1 + a_2 + a_3 + ---a_n$) feet.

$A \quad a_1 \quad A_1 \quad a_2 \quad A_2 \quad a_3 \quad A_3 \quad a_4 \quad ------ \quad An_1 \quad a_n \quad A_n$

Now with $A\ A_n$ as one leg of a right triangle and the distance ($a_1 + a_2 + a_3 + --- + a_n$) plotted to the same scale as the other leg $A_n\ B_1$ we have represented graphically a relief of ($a_1 + a_2 + a_3 + ---a_n$) feet in a distance of $A\ A_n$ miles. The average angle of slope may then be measured directly with a protractor, or it may be computed as follows:



$$\frac{B\ A_n}{A\ A_n} = \tan \alpha$$

$$\tan^{-1} \alpha = \frac{B\ A_n}{A\ A_n} = \text{average angle of slope of region.}$$

4. Complications due to Spacing as Complex Function.

With all the necessary data now taken, interpretations were formulated by making three graphs from the data of each rock type selected (shale and sand-stones, granite, shists, and lavas) one with spacing and angle as variables with the third factor, relief, recorded on the graph together with the name of region, the same was done for spacing and relief with angle noted, and for relief and angle with spacing noted (Plates XI - XIX) It is evident that these third variables gave rise to innumerable complications, making impossible the exactitude attainable by graphs when but two variables are concerned, but having the third variable noted on the graph gave a basis of comparison. For instance, if in the graph of spacing and relief the spacing of a certain region was too close for its given relief, as compared with the general average, the other factors of climate and angle, which were noted on the graph, would be considered and in many cases the discordance could be accounted for by a higher angle or by a difference in climate. In this way all the graphs received review, and generally speaking most irregularities could be explained by taking the third factor into consideration.

Another thing to be taken into account is the fact that in such a problem where the sources of data are often unreliable, and actual field observations impossible, the coefficient of error runs very high ruling, out all possibility of mathematical exactitude. Were there any method whereby Mother Nature could be controlled wholly or in part as is possible in a laboratory experiment the results obtained might be simple and easily interpreted, but when

dealing with a problem in nature, like this one, all the multitude of conditioning factors can not be controlled. Nevertheless these conditioning factors should not be overlooked in making interpretations. On the other hand conclusions drawn from a proper interpretation of such complex data need not be looked upon as worthless for they may express clearly the general laws, though exceptions may be numerous.

II RELIEF AS FACTOR.

1. Effect on Angle.

Now let us consider first the effect of relief as a factor in stream spacing. Penck says that spacing varies with angle and relief. It is therefore important to ascertain the effect of relief on the angle of slope. On any given formation it was found (see Plates 13, 16, 19) that the angle depends but little on relief, for with various reliefs we often find the same angle. Nevertheless on the whole it appears that on any single formation there is a general tendency toward slightly higher angles with increased relief provided the climate is uniform. But, where the increase in relief is accompanied by an increase in resistance of the rocks we find a considerable increase in the angle.

2. Effect on Spacing.

When we considered the effect of relief on spacing we found that on a given formation there was an increase in spacing with a perceptible increase in relief, and with any very marked increase in relief there was an increase in spacing irrespective of difference in rock character (see Plates 12, 15, 18). If the angles on any given formation had remained constant despite variations in relief, the spacing would have necessarily increased in direct

proportion to the increase in relief as shown in Figure A, however, as noted before, increased relief gave a slight increase in angles an and thus a tendency to closer spacing. However, it appears that this latter tendency was not strong enough to entirely neutralize the increase in spacing due to increase in relief and we found relations as expressed in Figure B.

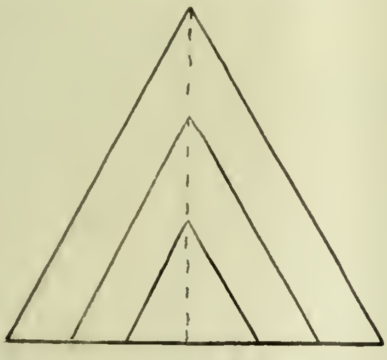


Figure A

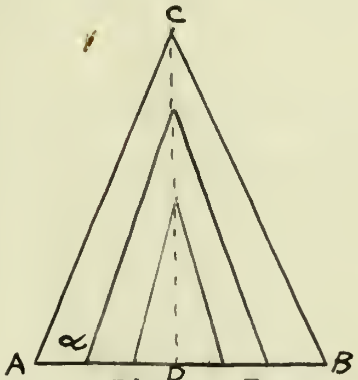


Figure B

Somewhat the same relations were set forth by Penck only he says that the maximum height of watershed is accompanied by a maximum angle of 30° which gives a spacing of three and one half times the height of watershed as borne out in the following formula.

$$\left[CD = \frac{AB \tan 30^\circ}{2} \right]$$

That 30° really is the maximum angle of repose is quite probable as we found few angles above 20° and the very maximum 29°

3. <u>In Relation to Rock Character</u>.

Since relief is produced chiefly through crustal movements, there seems no very apparent reason why different formations should vary in relief, but nevertheless, in our own data the more resistant formations, such as granite, schist, and lavas, were accompanied by higher relief than those on weaker rocks such as limestone, shales and coarse sandstones. (Plates 12, 15, 18.)

This may, in some measure, be explained by the fact that the divides

on the weaker rocks are not able to maintain themselves at the same height that they can on harder rocks, and thus, as the streams cut down, the divides on harder rock resist weathering and give greater relief, or it may be that it is but a matter of chance data.

III ROCK CHARACTER AS A FACTOR.

1. Effect on Angle.

In coming to the second factor determining stream spacing, that of rock character, the first thing that strikes our attention is that the more resistant the rocks the greater the angle of slope and vice versa. (Plates 13, 16, 19.) Too, in considering any single formation there seems to be quite a striking uniformity of angles (Plates 11, 14, 17) and this quite agrees with Shaler's remark that there is an effective angle of side slope, which is determined by the character of the materials being eroded. Along with this higher angle for harder rocks is combined a tendency to higher relief, (Plates 12, 15, 18) although, as said before, this coincidence of higher relief with harder rocks may have been merely due to choice of data. However the wider spacing due to increase in relief is in a sense more or less equalized by any tendency toward closer spacing in response to steeper angles produced by higher relief.

Some mention has now been made concerning the spacing of streams in relation to the relative resistance of the formations, but aside from relative resistance the question of perviousness plays quite as important a role. In case of a pervious formation and an imperviousness one of the same relief, more of the rain is absorbed by the pervious rock and thus the run off and the number of streams are deminished, giving a more open spacing on the pervious

than on the impervious formation. If the angle and relief are very high then the effect due to variations in perviousness is reduced to a minimum, because the rain does not lie on the surface long enough to penetrate even the more pervious rock, but augments the run off. The stream texture under these conditions is not considerably different on the rocks of varying porosity. This idea is similar to that brought out by W. M. Davis in "Systematic Descriptions of Land Forms",(8) where he says that pervious strata produce a smaller number of streams than impervious and fine grained materials, and that the latter, under conditions of aridity and scanty vegetation, produce fine texture in youth, and in early maturity the characteristics of bad land topography. In consequence of these responses to variations in rock character we can conclude that generally speaking, resistant impervious formations are accompanied by closer spacing, steeper angles and higher relief than weak pervious strata.

IV. CLIMATE AS A FACTOR.

1. Effect on Angle, Relief and Spacing.

In coming to a consideration of the third main factor, that of climate, we are confronted by a factor which at first glance may seem trivial and easily disposed of, but which, when one recalls the many sub-factors entering into it, seems appalling in its complexity. For instance, one must not only reckon with all the elements of wind, percipitation, temperature, seasonal changes and so on, but with all their manifold details and combinations as for example, "What time of the year does the greatest percipitation occur?", and "Is it in the form of ice, snow or rain?".

(8) Davis, W.M., Geog. Jour. pg. 307 :1909

It is readily seen that without a more detailed and far reaching investigation only the more general conclusions of the effect of such a complex factor as climate can be deduced. When we view the drainage patterns of two sections one in a humid and the other in an arid region we are confronted by two rather different samples of drainage texture. First of all the scanty precipitation and excessive evaporation in an arid region gives, on the whole, a poorly integrated system of drainage with the large streams far apart while the reverse of the above conditions in a humid region produce opposite effects. This above applies chiefly to the main streams, for when we examine an arid region with high relief, scanty vegetation, and impervious strata we find the drainage system quite as elaborately worked out as any in a more humid region. One difference however, is that most of the streams are inter - mittent in place of permanent as in a moist climate. This difference is no doubt due to the fact that the cloud-burst type of storms, characteristic of the desert, infrequent as they are, are more effective in developing stream courses on the exposed materials than a much heavier rainfall on soils protected by heavy vegetation.

In truth it is difficult to make a brief but comprehensive study of the effect of climate on stream spacing. For instance, in any arid region the scanty vegetation and extremely effective action of the wind in wearing down the slopes and depositing the waste in the hollows, as well as the gouging out of new basins, are but a few of the numerous factors to be regarded in looking for reasons for the specific drainage texture found in such regions. In summarizing our observations on this point, there seems no just

ground to say that aridity produces very open spacing and humidity very close as is so often brought out, for while such is the case of regions of low relief, nevertheless in arid regions of high relief, scanty vegetation and impervious rocks the drainage is as intricate as any in humid regions. What we can say is, that in arid regions of low relief the drainage systems are more poorly integrated, trunk streams fewer with lower angles and wider spacing than in similar regions in a humid climate.

V. GENERAL INTERPRETATIONS.

1. Spacing due to declivity, rock character and climate.

Up to this point the interpretations have been restricted to the rather specific results noted as due to each factor, rock character, relief and climate taken as individual units. Now a short discussion might well be given to a more general interpretation of the results of these three factors not so much as separate entities but as elements in a cyclic function of stream spacing. Let us preface this more general treatment with the repetition of the idea that erosion is determined by the rock character, declivity and climate, and since any change in erosion changes the alignment and spacing of streams, then the spacing is necessarily determined by the above three factors. What is now needed to give a more comprehensive idea of the problem is a study of the relative importance of each determining factor, for so far we have merely noted the absolute effects and disregarded the relativity of values.

Taking first the general problem of the relation between spacing and rock character let us see what complications arise with variations in climate and relief. With weak pervious rocks there

is a great tendency to open spacing because weak rocks give low angles and pervious rocks give small run off, and so if to this combination is added an arid climate and moderately high relief we get the maximum conditions for an open drainage texture. However, if any one of these factors vary from this value set for maximum spacing there is a new problem set to determine the relative results due to variations of this factor. For instance, if you found a region of medium high relief and pervious rocks, - both of which tend to wide spacing - but found that on the contrary it has a close spacing you could quite legitimately conceive of its being due to an abnormally resistant rock. If by checking with original data you found that this assumption was not borne out by the facts, then the question of climate might be considered, as close spacing might be due quite as well to an unusually humid climate as to a more resistant rock. However, if under the same conditions of relief and rock character as the above you should find an abnormally low angle and wide spacing you would at once know that the region had gone beyond maturity.

As a result of the use of such methods of reasoning we found that weak pervious rocks gave wide spacing and hard impervious rocks gave close spacing under the same conditions of climate and relief, but variations toward aridity and slightly higher relief increased the spacing. Furthermore it appears that climate is a greater and more effective determinant than relief.

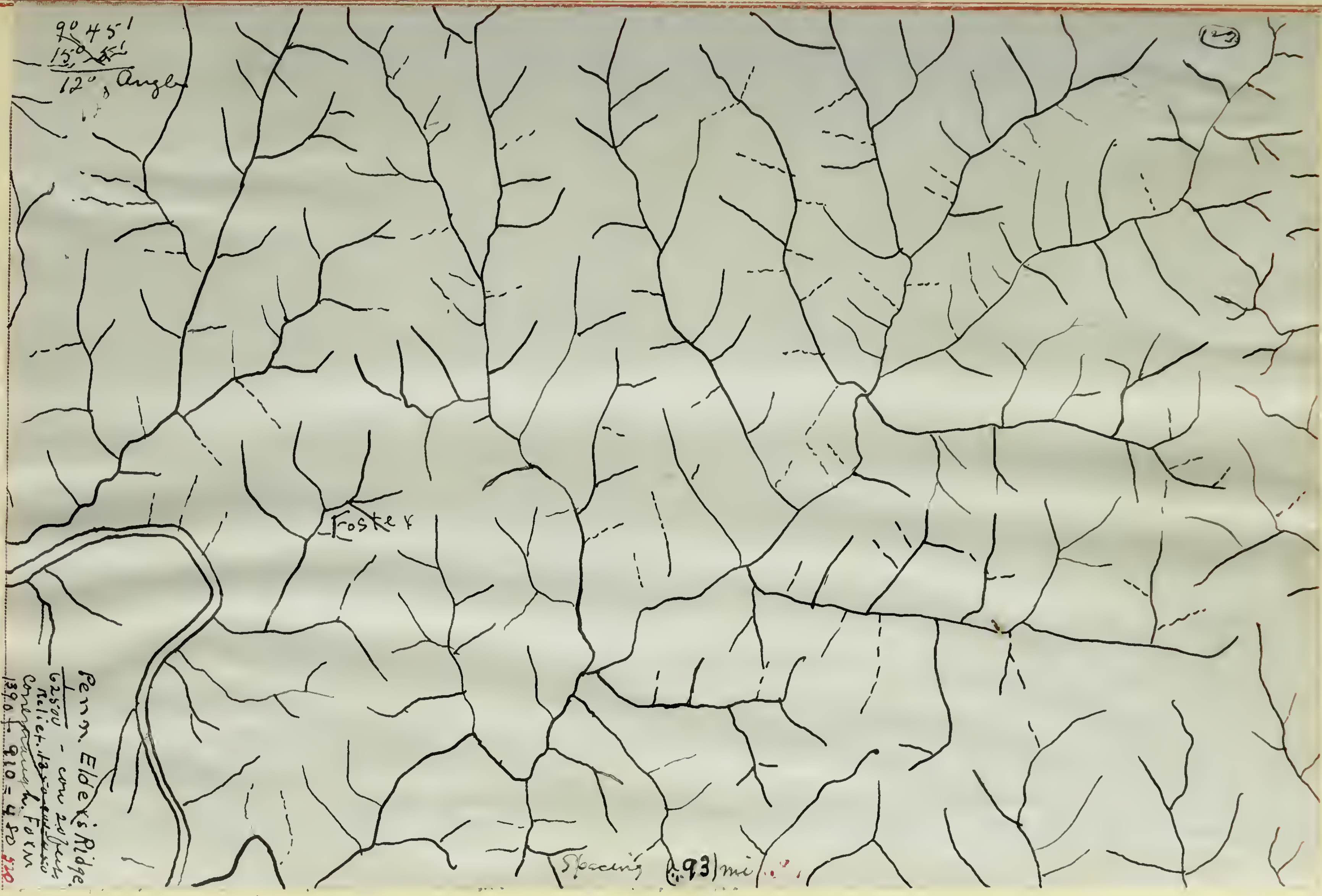
Now when we take spacing in reference to climate the greater spacing of trunk streams normally associated with an arid climate can be entirely revolutionized by the presence of a resistant im-

pervious formation or a higher relief with higher angle, or a combination of the two. While before, the climate seemed a determinant of greater value than relief here the dominance of the climatic factor is not so clear.

As noted before, there is a general coordination between relief and spacing yet here too, we must reckon with the remaining factors, climate, formation and angle of slope. With increase of relief there is an increase in general spacing, and too, with increase of relief there is generally a slight increase in angle, which tends to reduce the spacing, and counteract, in a measure the increase in spacing due to increase in relief. As a result of this, when on a given formation we find no increase in spacing with increase of relief we may find that the increase in angle is responsible for the phenomenon, reducing the effect of relief on spacing to a minimum, but in general cases it was not found to exert such a strong balance. If we find that, accordint to actual data, the above explanation for no increase in spacing with increased relief is not the correct one, we might explain it by slight differences in rock character. The ones of higher relief might be on impervious rocks, those of lower relief on pervious rocks, or both combined which would tend to minimize the differences of spacing with different reliefs. Then too, the areas of higher relief might be on slightly harder outcrops of the same formation which would give closer spacing and might throw the regions of high relief into the same class with ones of lower relief so far as spacing was concerned.

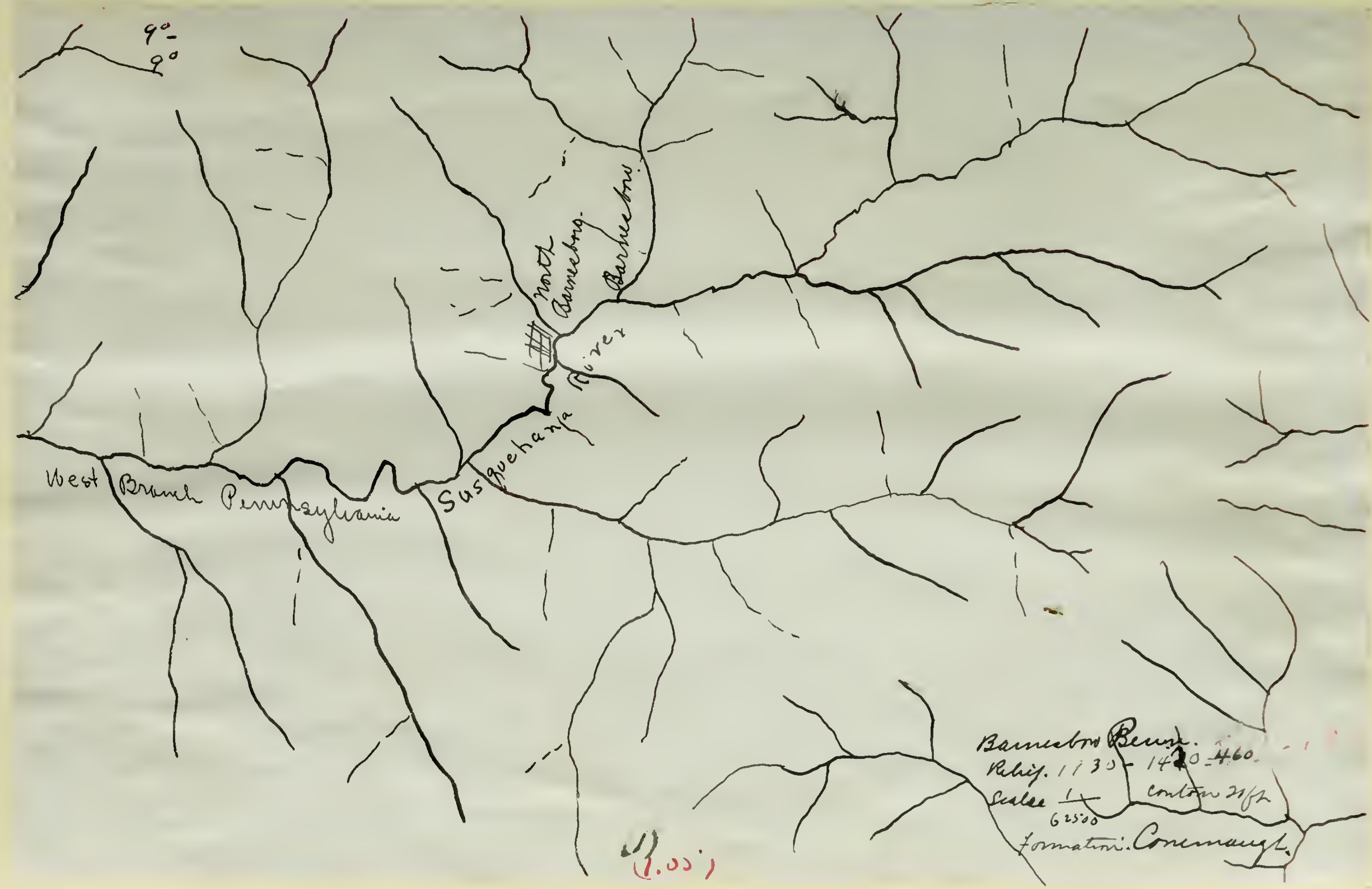
VI. CONCLUSION.

In conclusion: This investigation is little more than a beginning in an exceedingly complex problem. It seems to show however, that spacing of streams is not so directly dependent on relief as it is on climate and the character (including resistance and porosity) of the materials being eroded. It is here that the problem must be left at present. It is hoped however, that this may pave the way for a more far reaching study which, based on more extensive and authentic data, especially field observations, may lead to as conclusive and precise results as any in the field of the dynamic forces of nature.



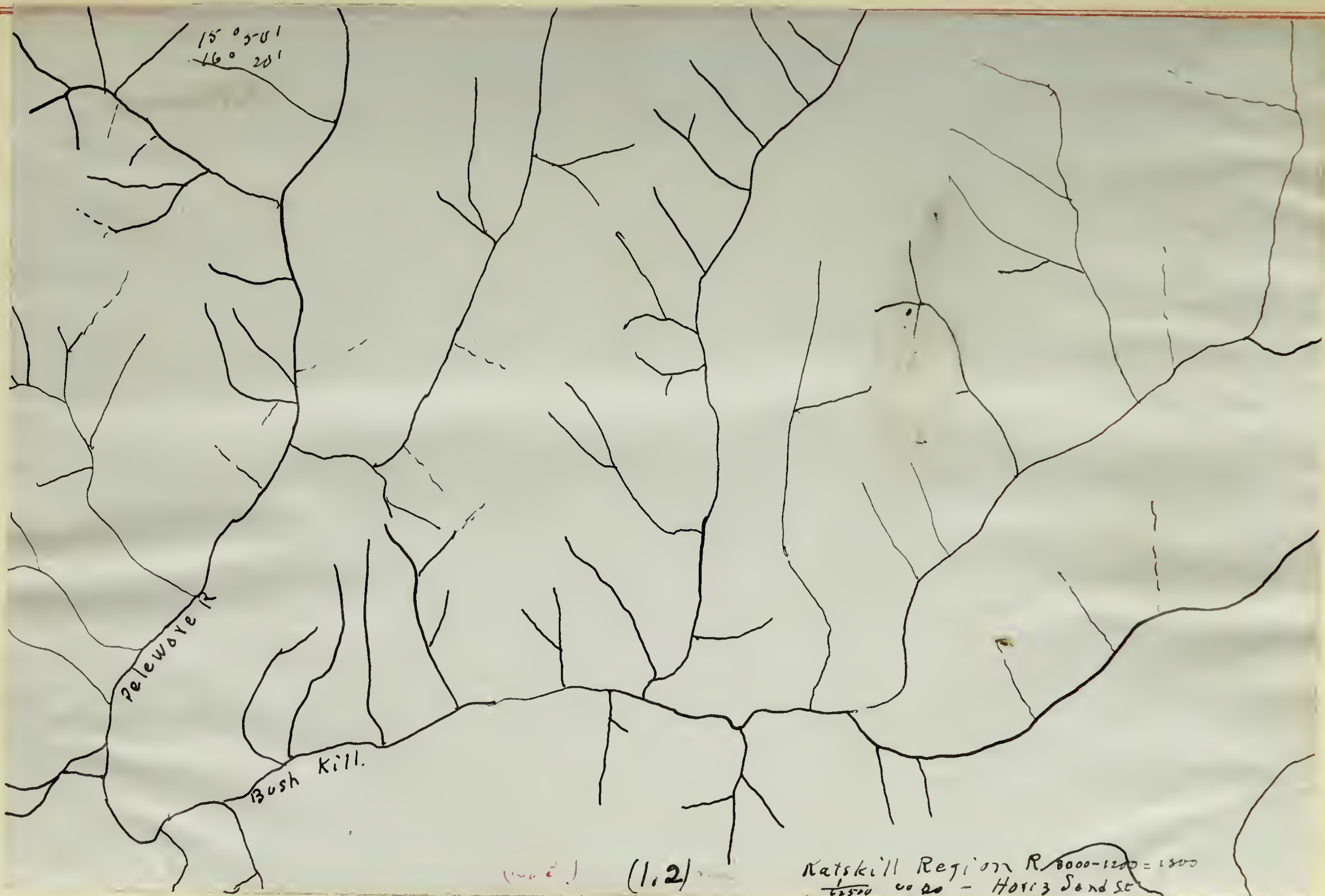
Elders Ridge Pa.
Conemaugh Formation (Shales and soft sandstones
Relief 480 ft. Angle 12
Spacing .93 mi.

Plate 1



Barnesboro Pa.
Conemaugh Formation (Soft sandstones and shales)
Relief 460 ft. Angle 9 Deg.
Spacing 1 mi.

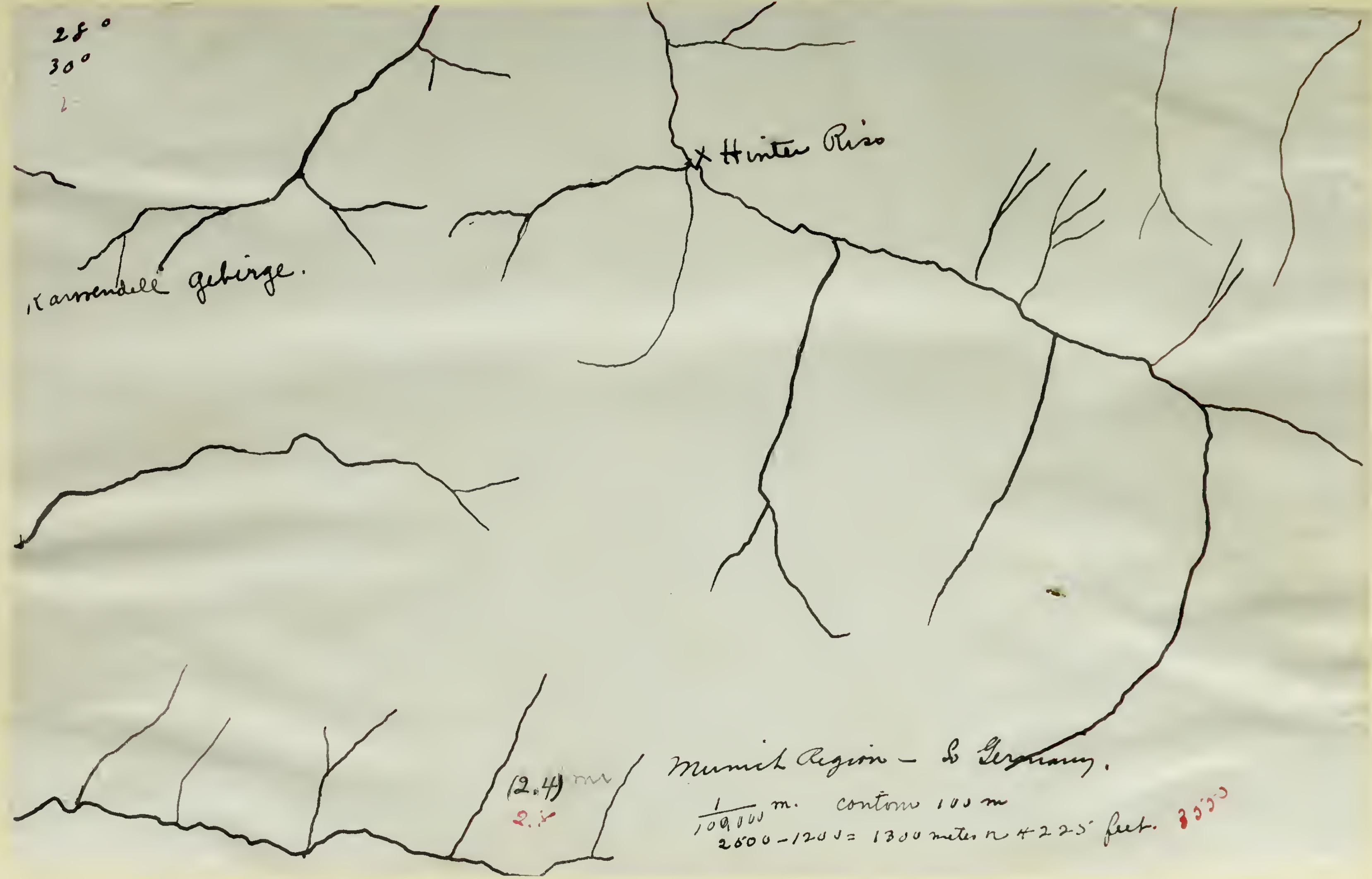
Plate



Katskill Region N.Y.
Horizontal Sandstones (hard)
Relief 1800 ft. Angle 16
Spacing 1.2 mi.

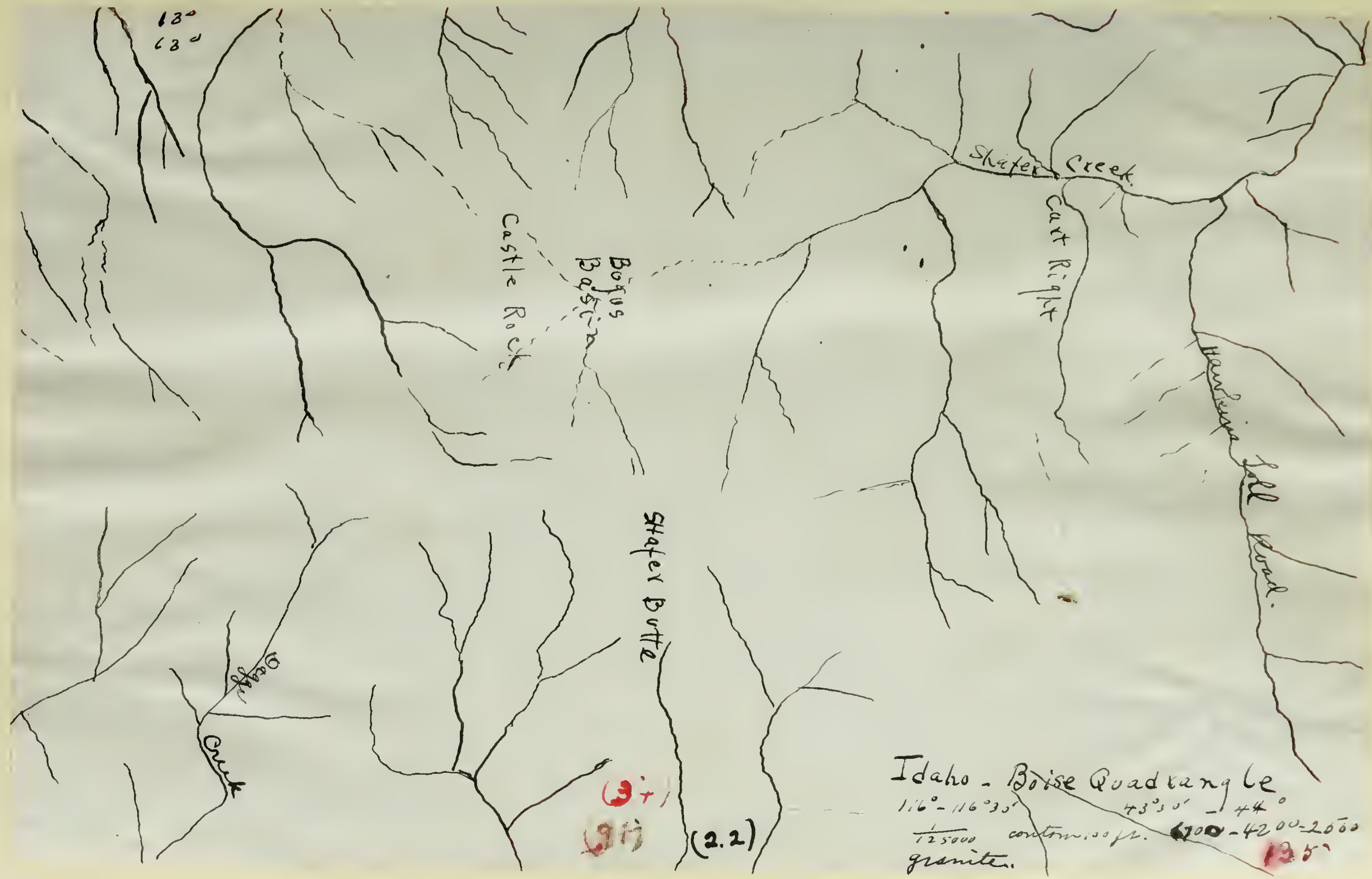
Shows high angle
with high relief
and hard rocks

plate 3



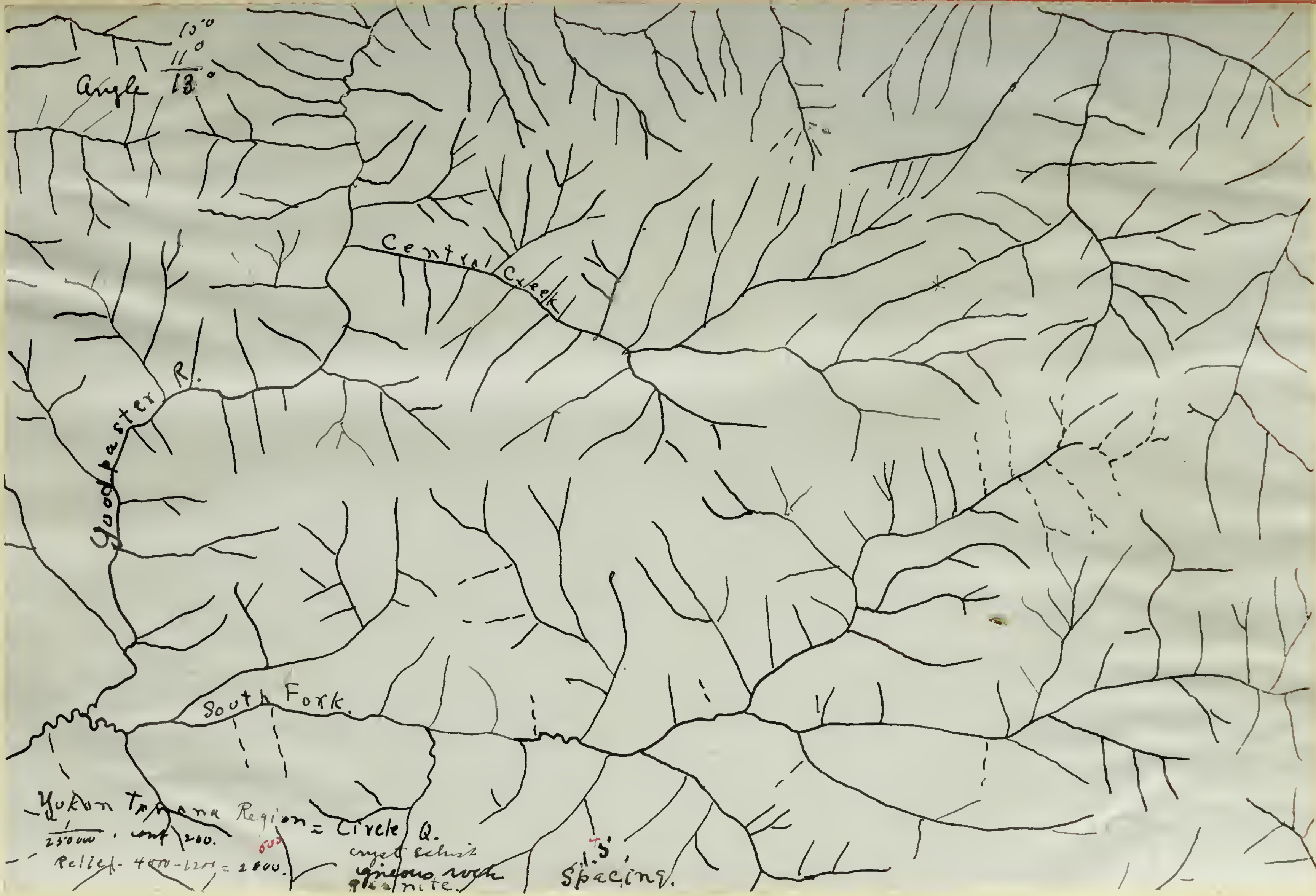
Shows maximum angle with high relief.
Plate 4

Munich Region So. Germany.
Granite
Relief 4225 ft.
Spacing 2.2 mi.
Angle 29 degrees



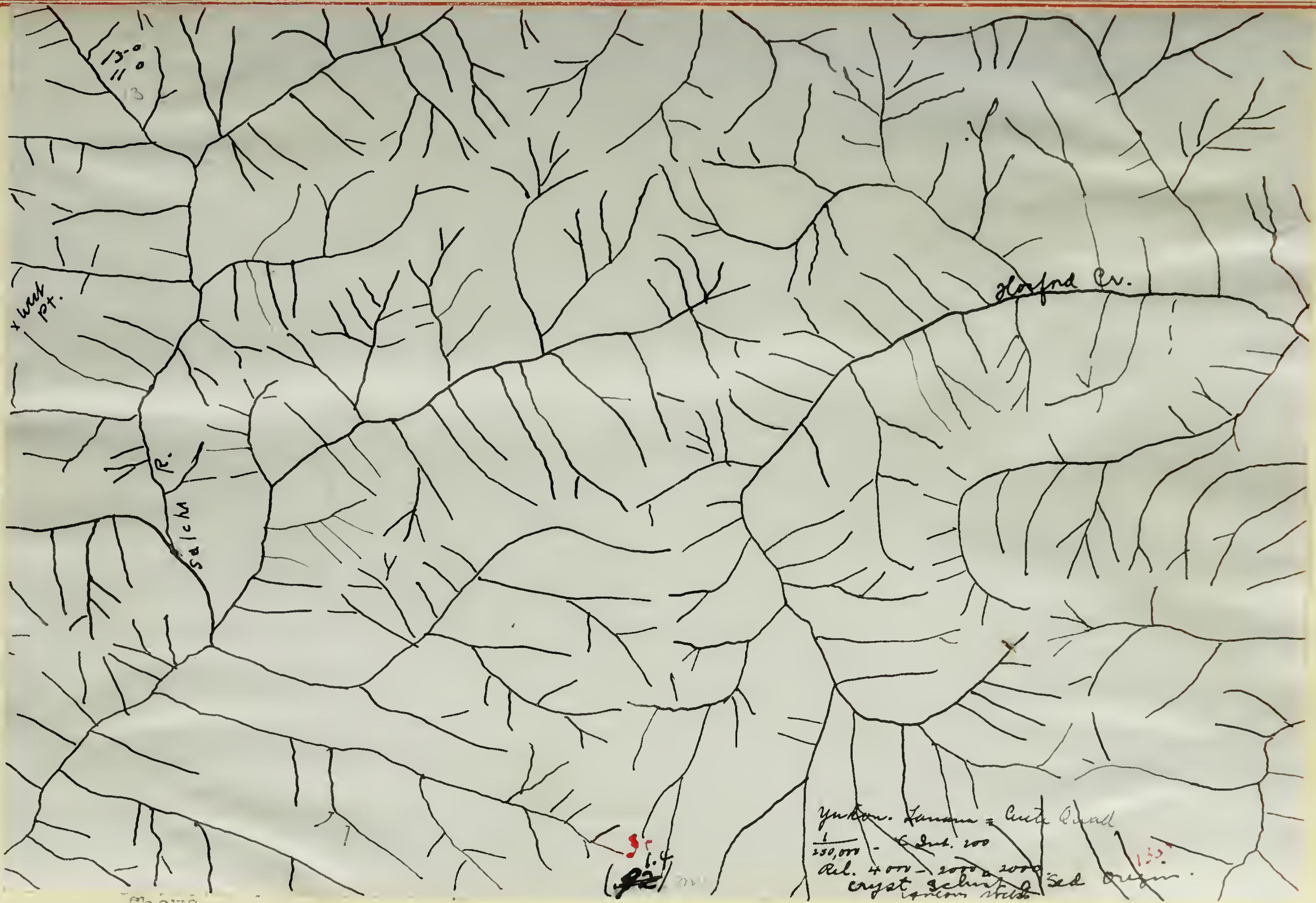
Boise Idaho
Granite
Relief 2500 ft. Angle 13degrees
Spacing 2.2 mi.

Plate 5



Yukon Tanana Alaska
Crystaline shists and Granites
Relief 2800 ft.
Angle 13 De.
Spacing 1.8 mi

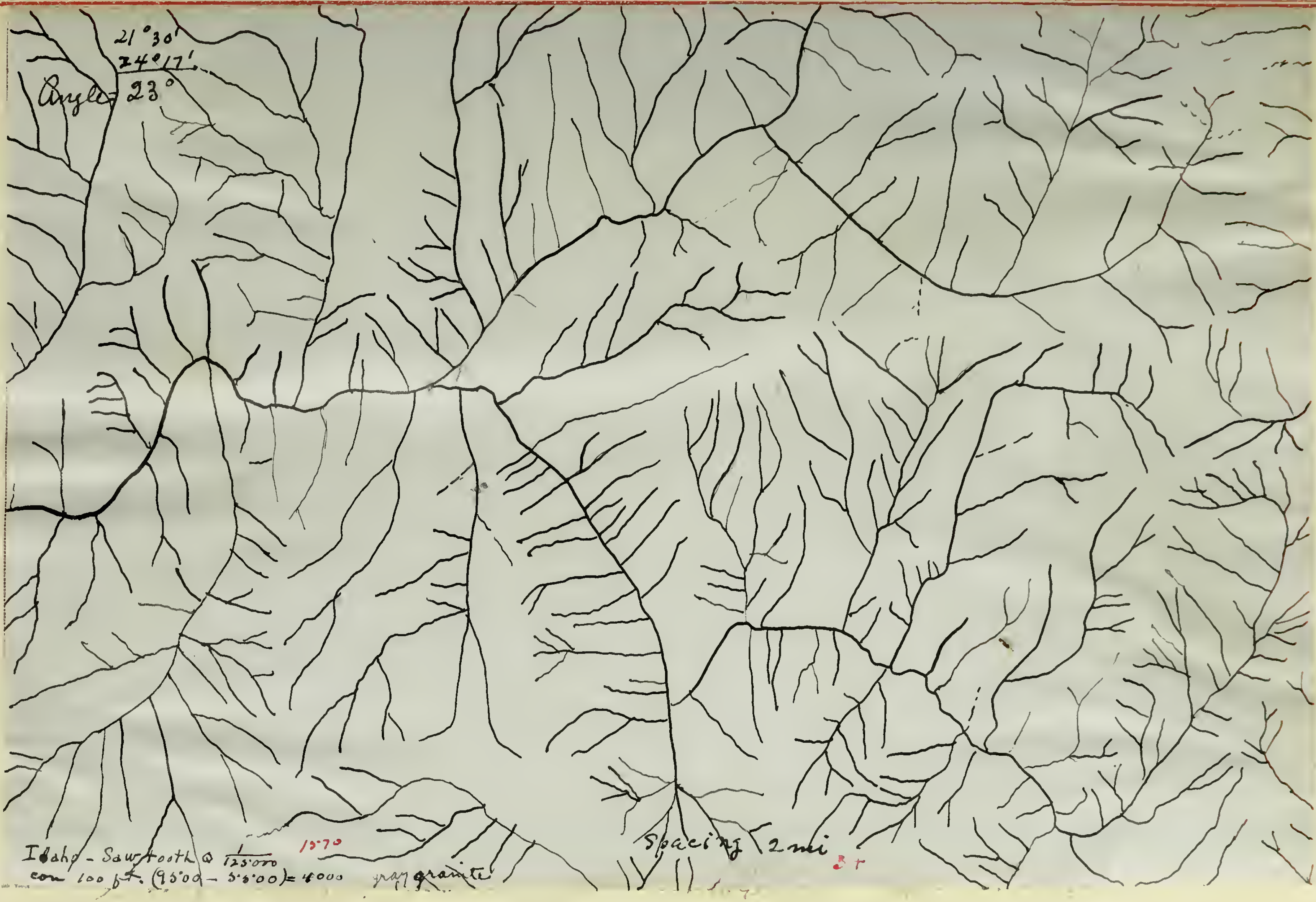
Plate 6



Shows
structural
control

Yukon Tanana Alaska
Crystaline Shists of sedimentary origin
Relief 2000 ft.
Angle 13 Deg
Spacing 1.4 mi.

Plate 7

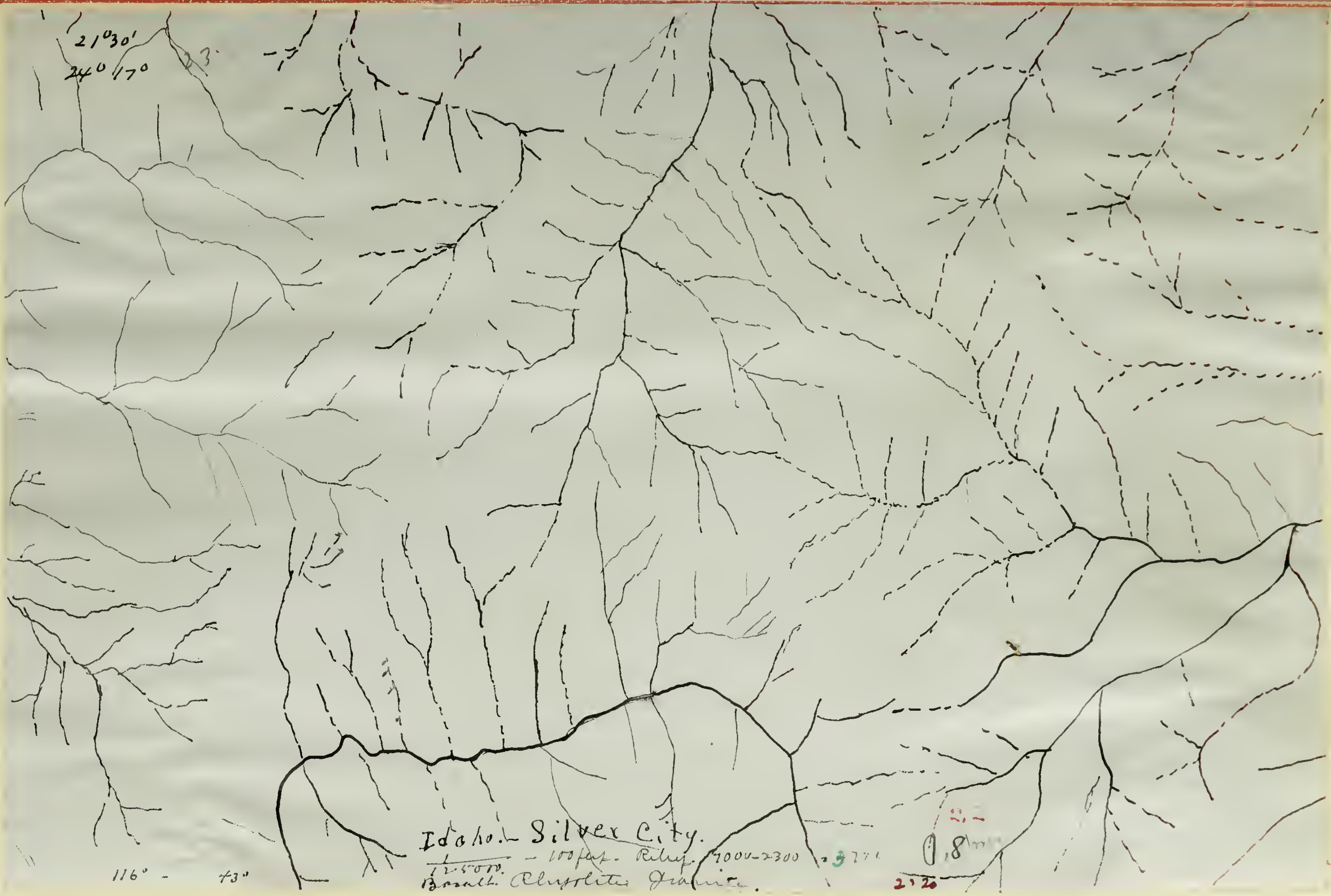


Shows
structural control

Sawtooth Idaho
Granite

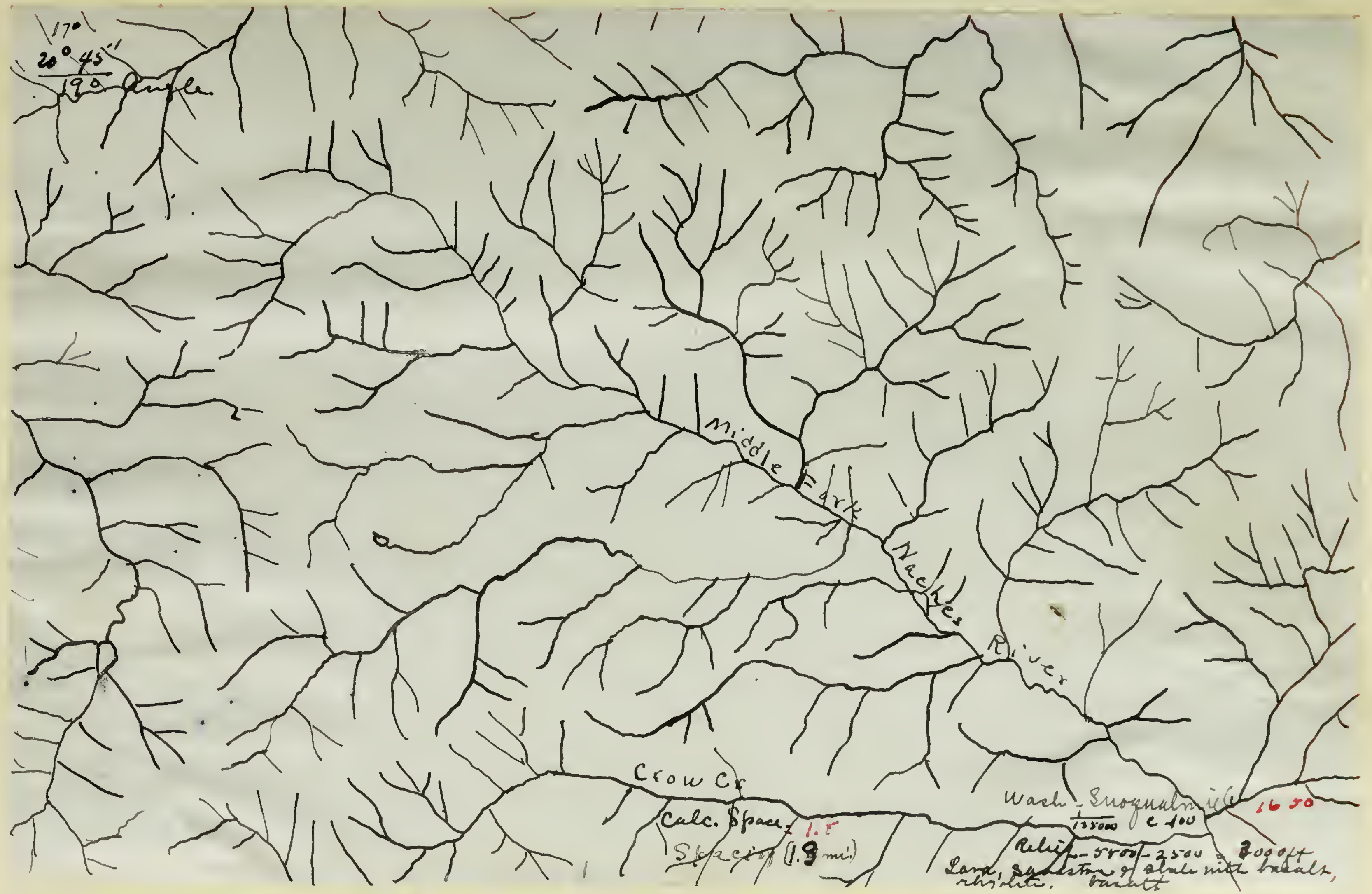
Relief 4000 ft. Angle 23Deg.
Spacing 2 mi.

Plate 8



Silver City Idaho
Lava - Basalt - Rhyolite
Relief 3750 ft.
Angle
Spacing 1.8 mi.

Plate 9



Snoqualmie Washington

Lavas - Rhyolite - --- Basalt

Relief 3000 ft. Angle 19 Deg.

Plate 10 Spacing 1.3 mi.

Shales — Sandstones

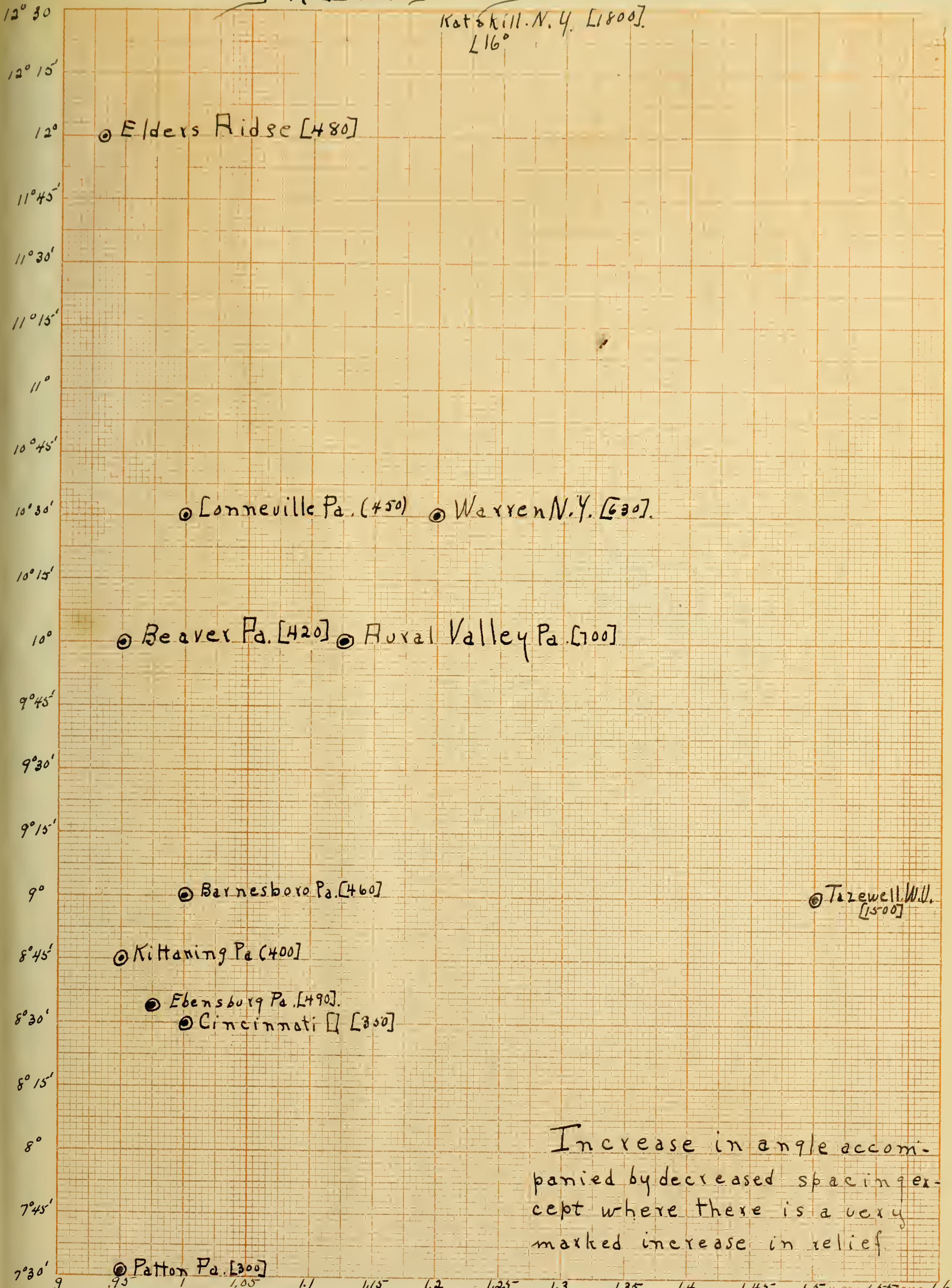


Plate XI Spacing — Angle

Shales – Sandstones.

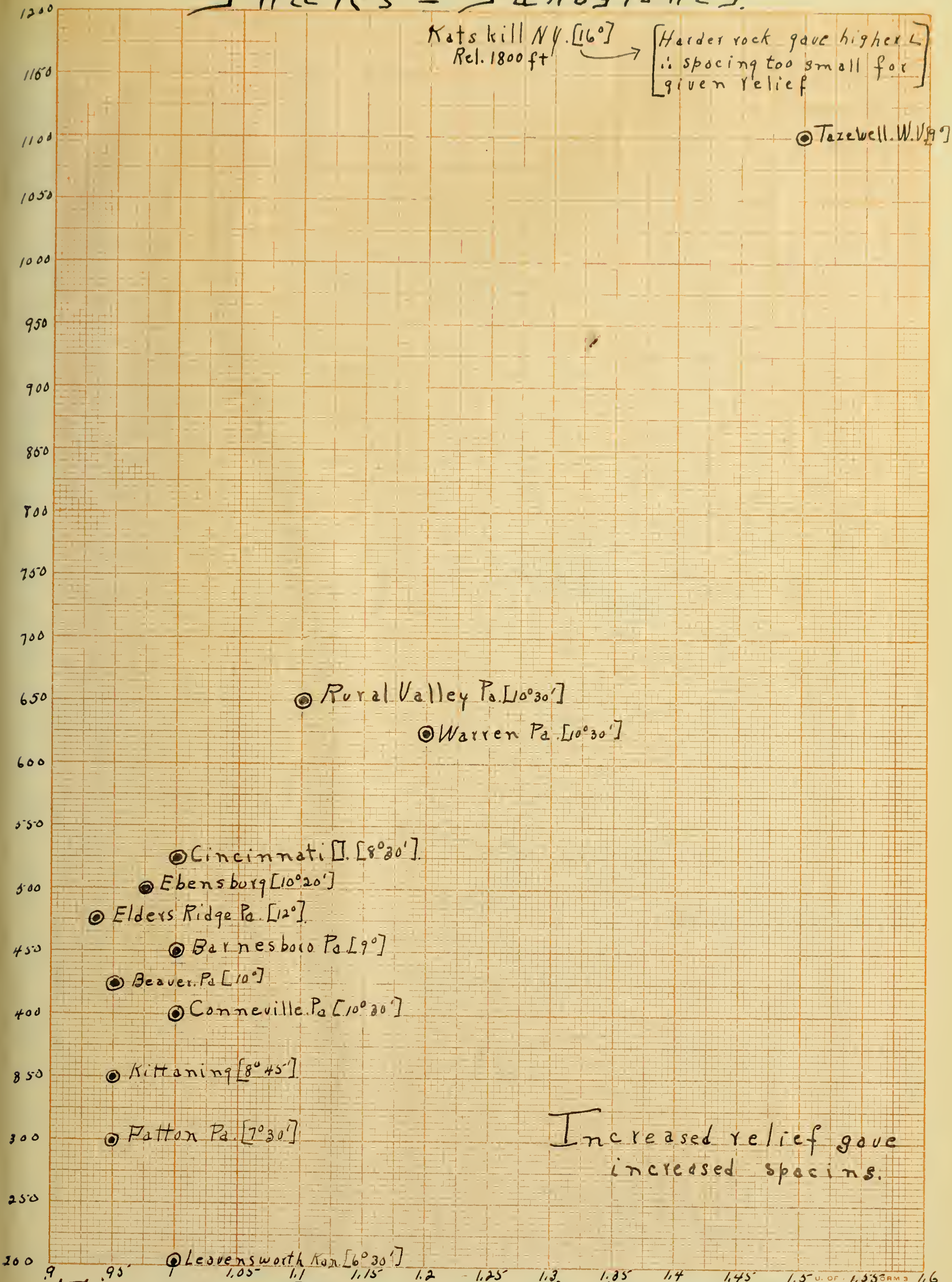


Plate XIII Spacing – Relief.

Shales - Sandstone.

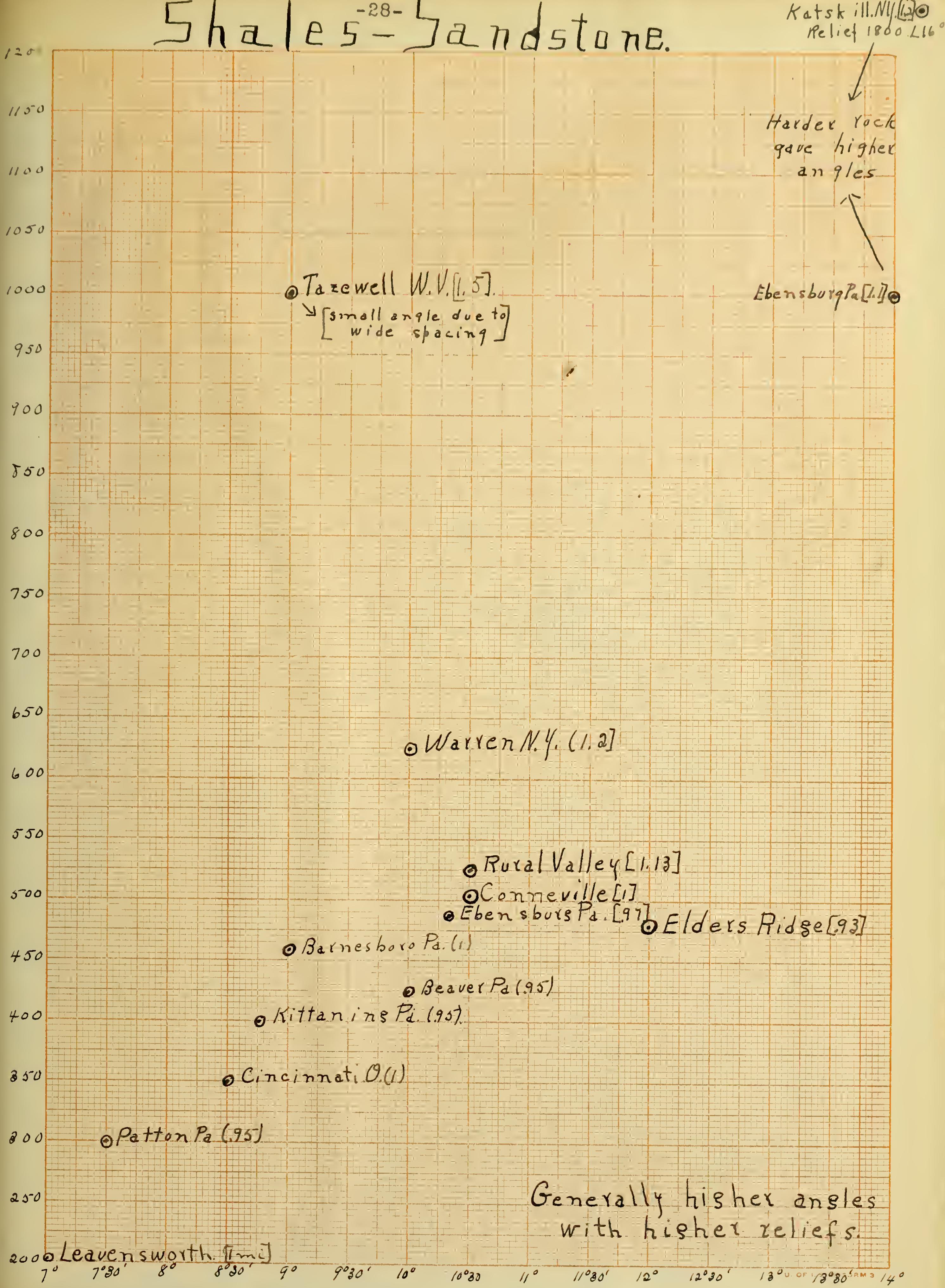


Plate XIII Relief — Angle

Granite – Schists.

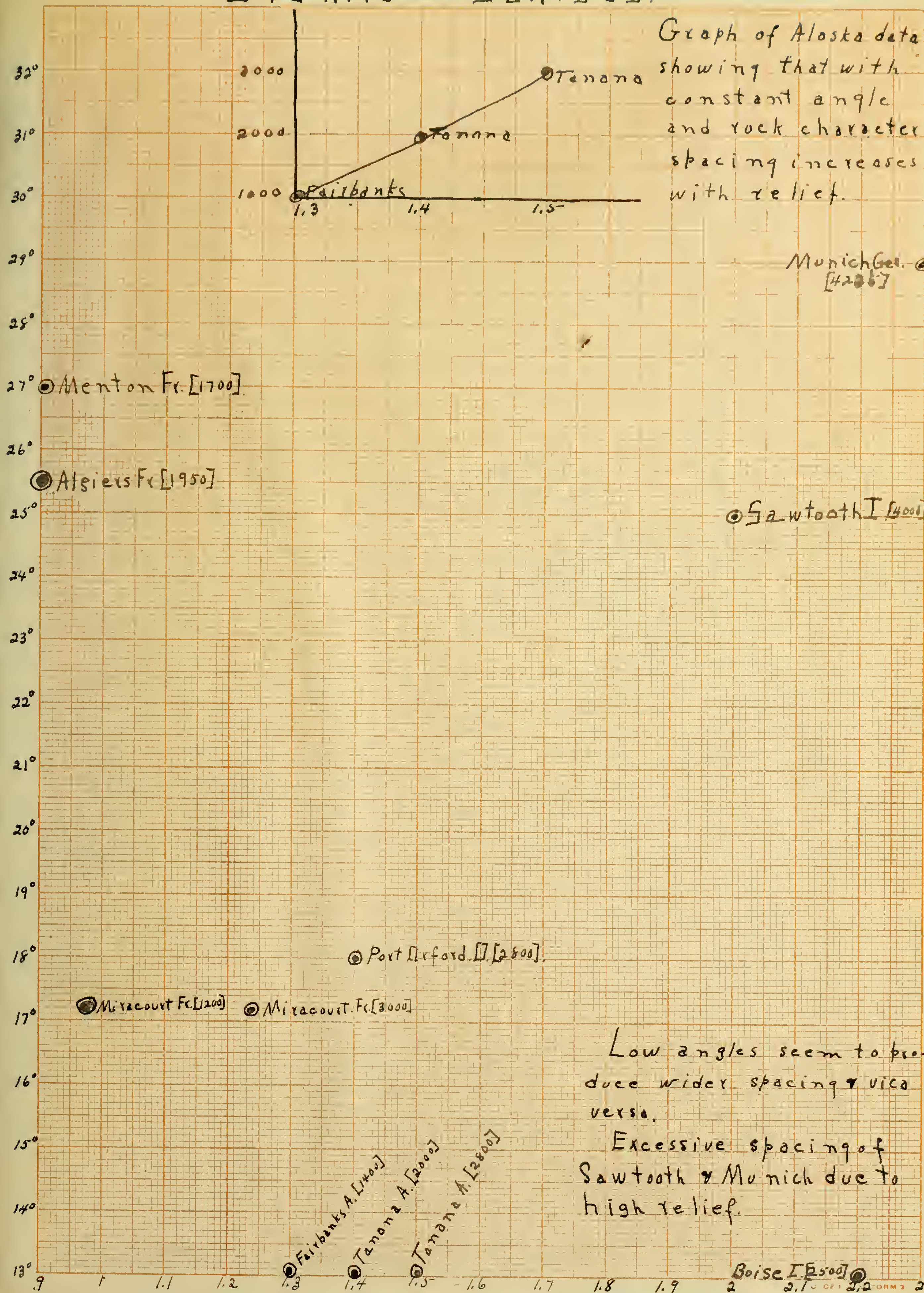


Plate XIV Spacing–angle

Granites -30- Schists

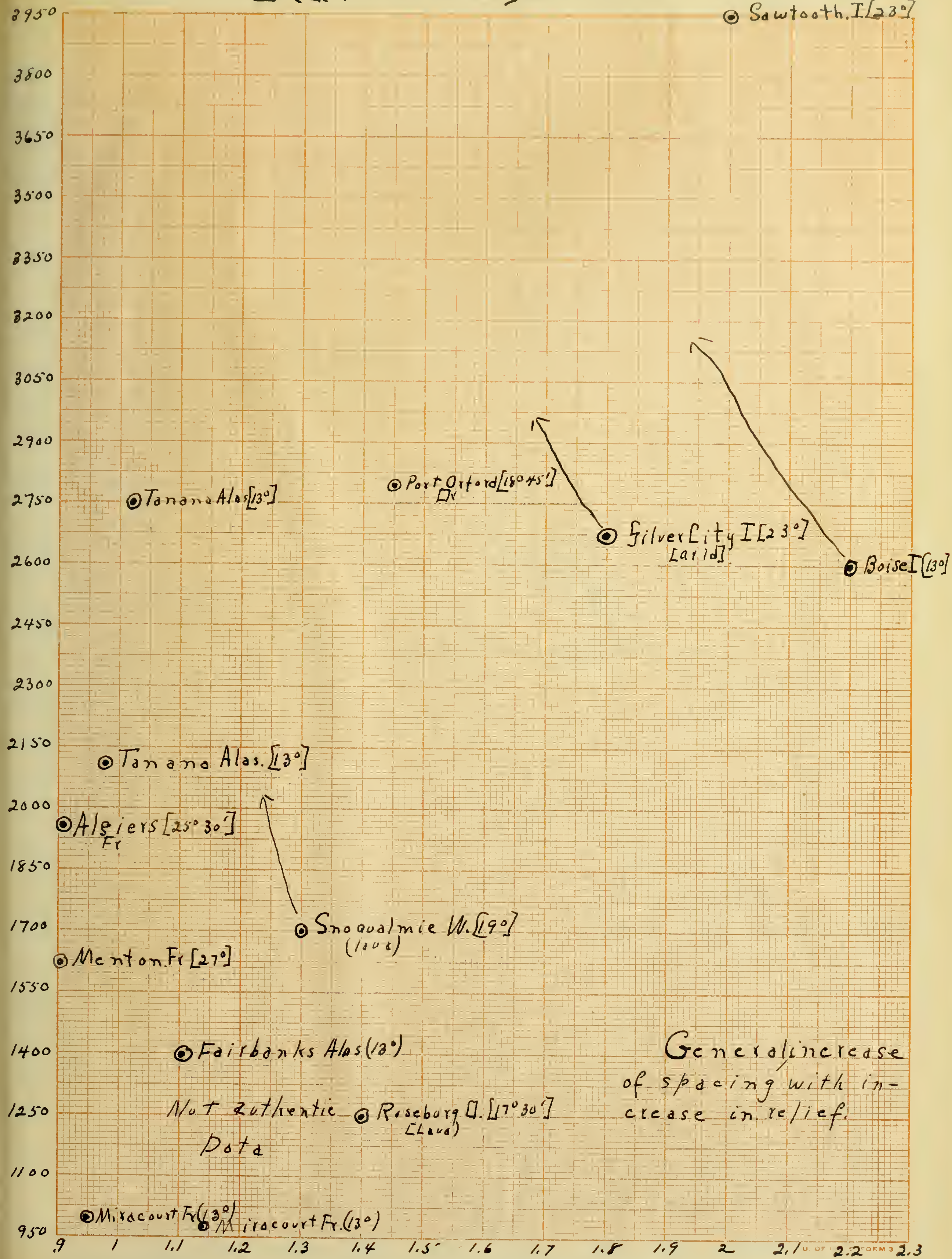


Plate XV

Spacing - Relief.

Granites -31- Schists.

Munich Ger ⊙ [3.4]

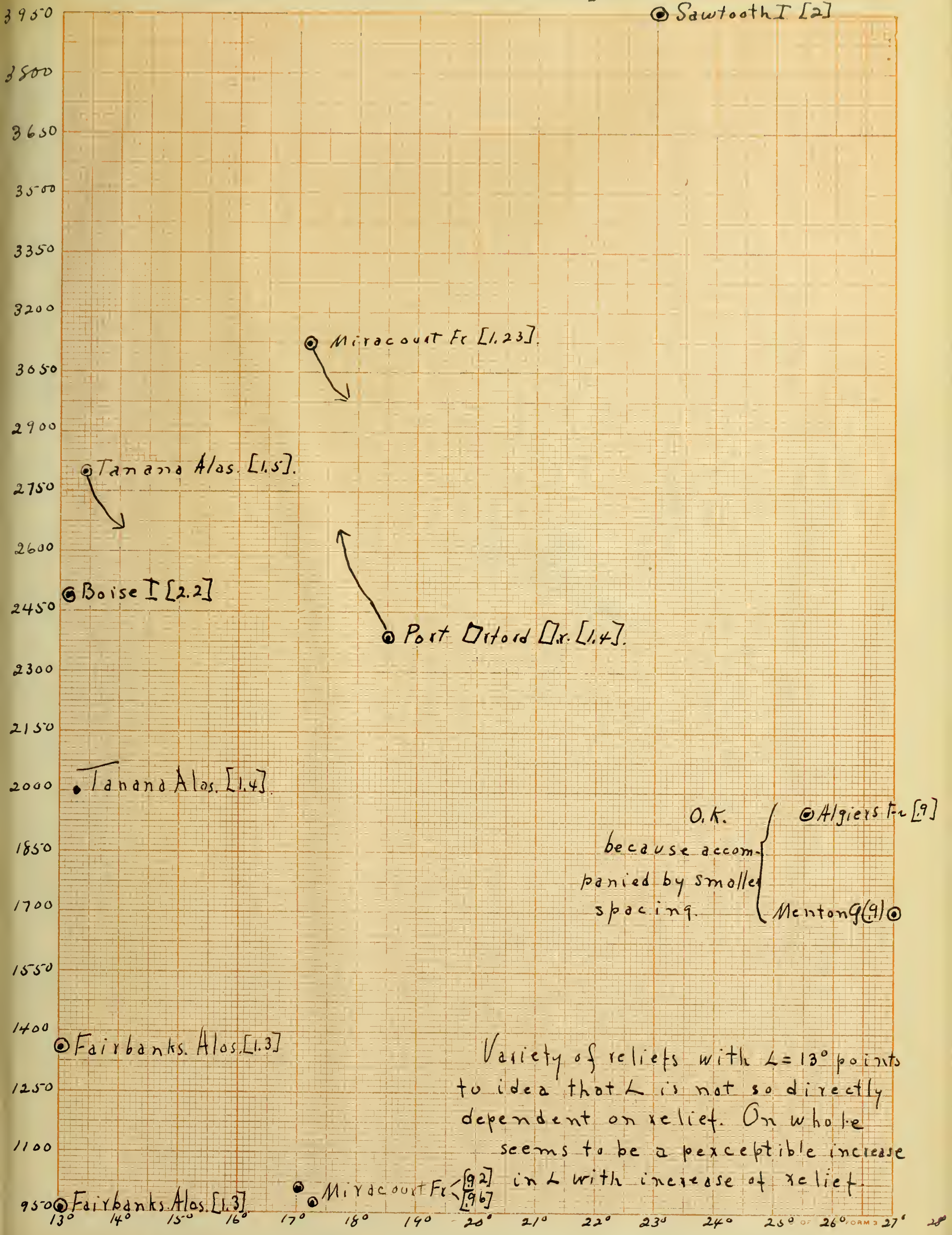


Plate XII. Relief - Angle.

Lava.

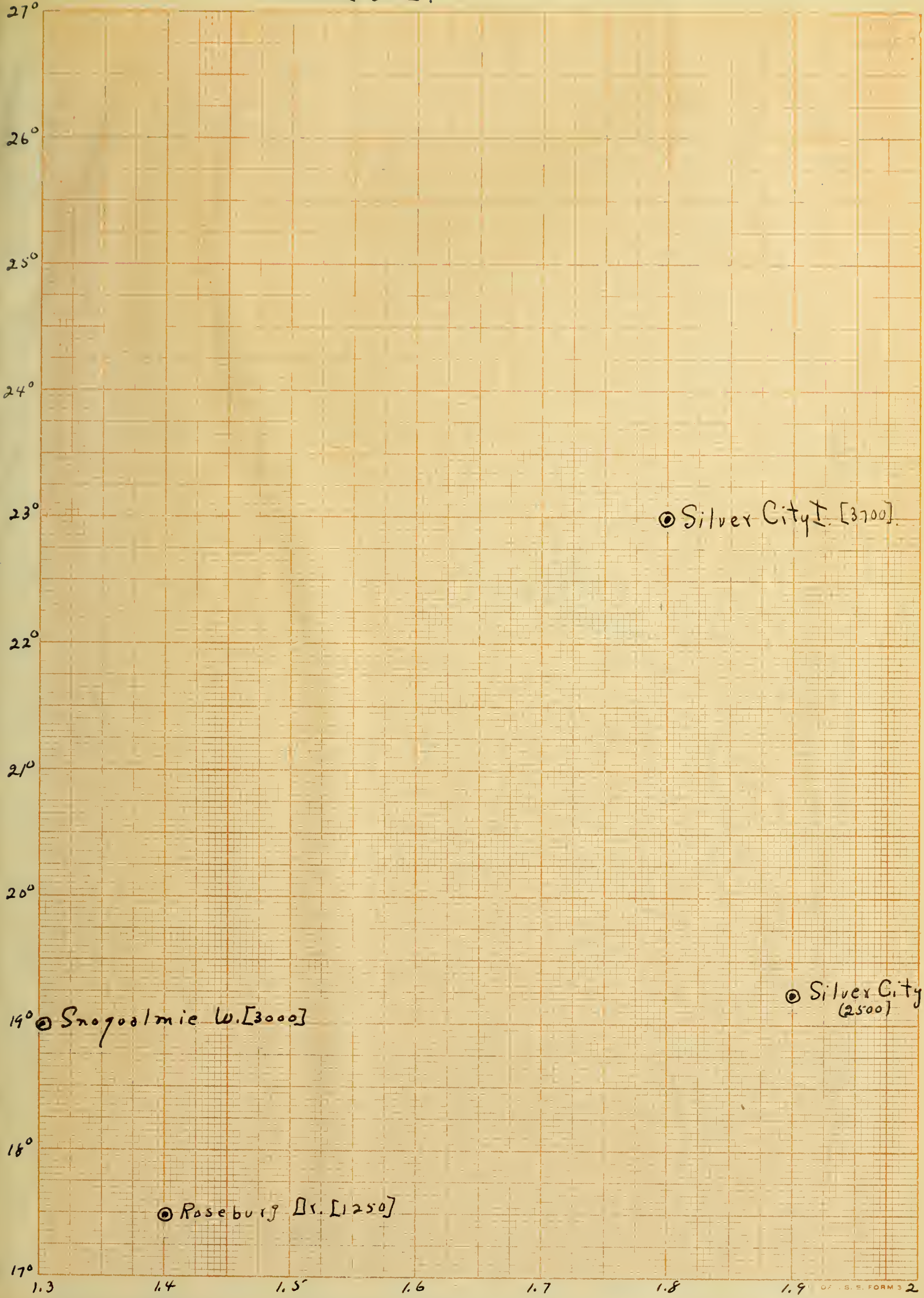


Plate XVII

Spacing-Angle.

Lava

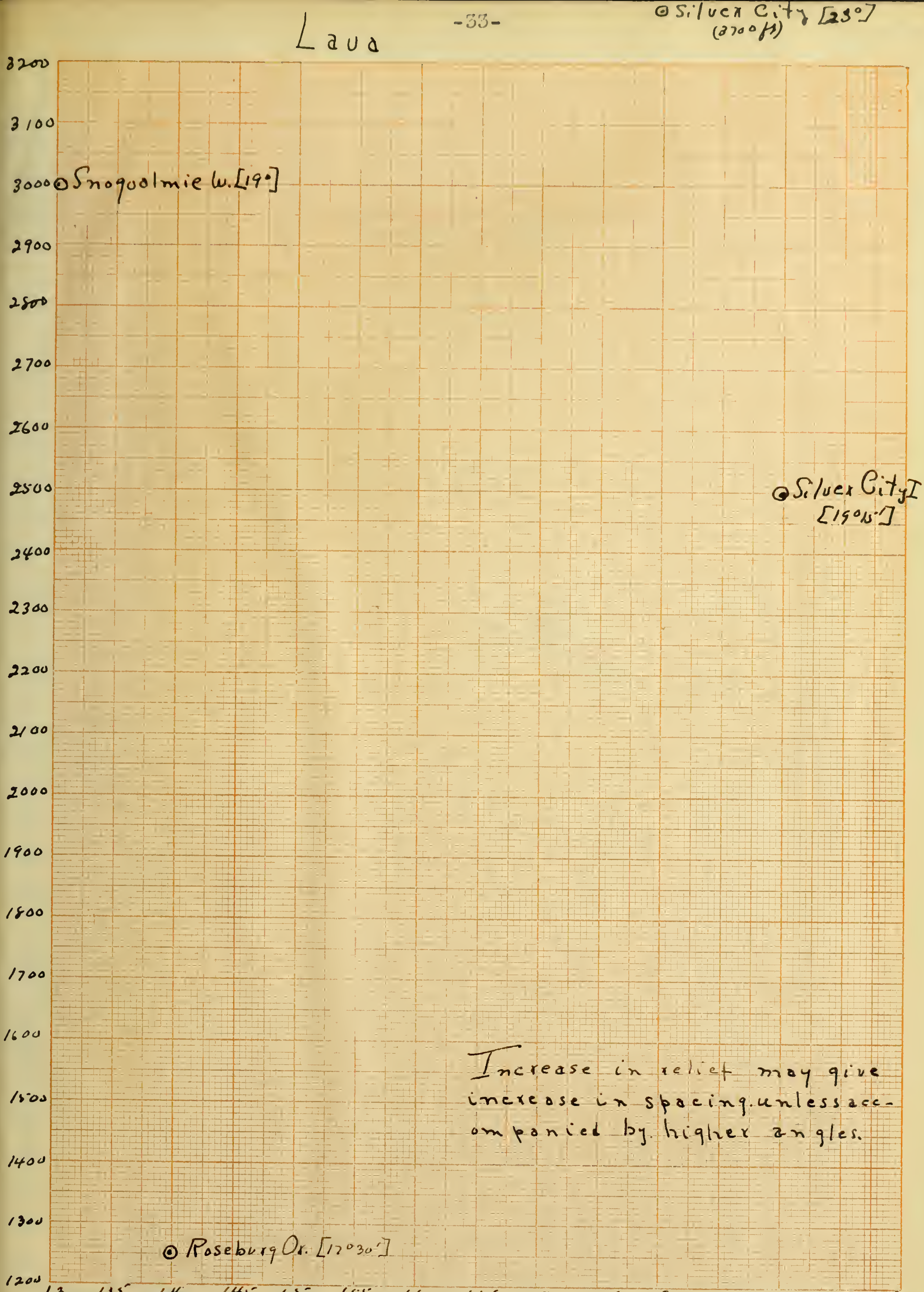


Plate XVIII Spacing-Relief.

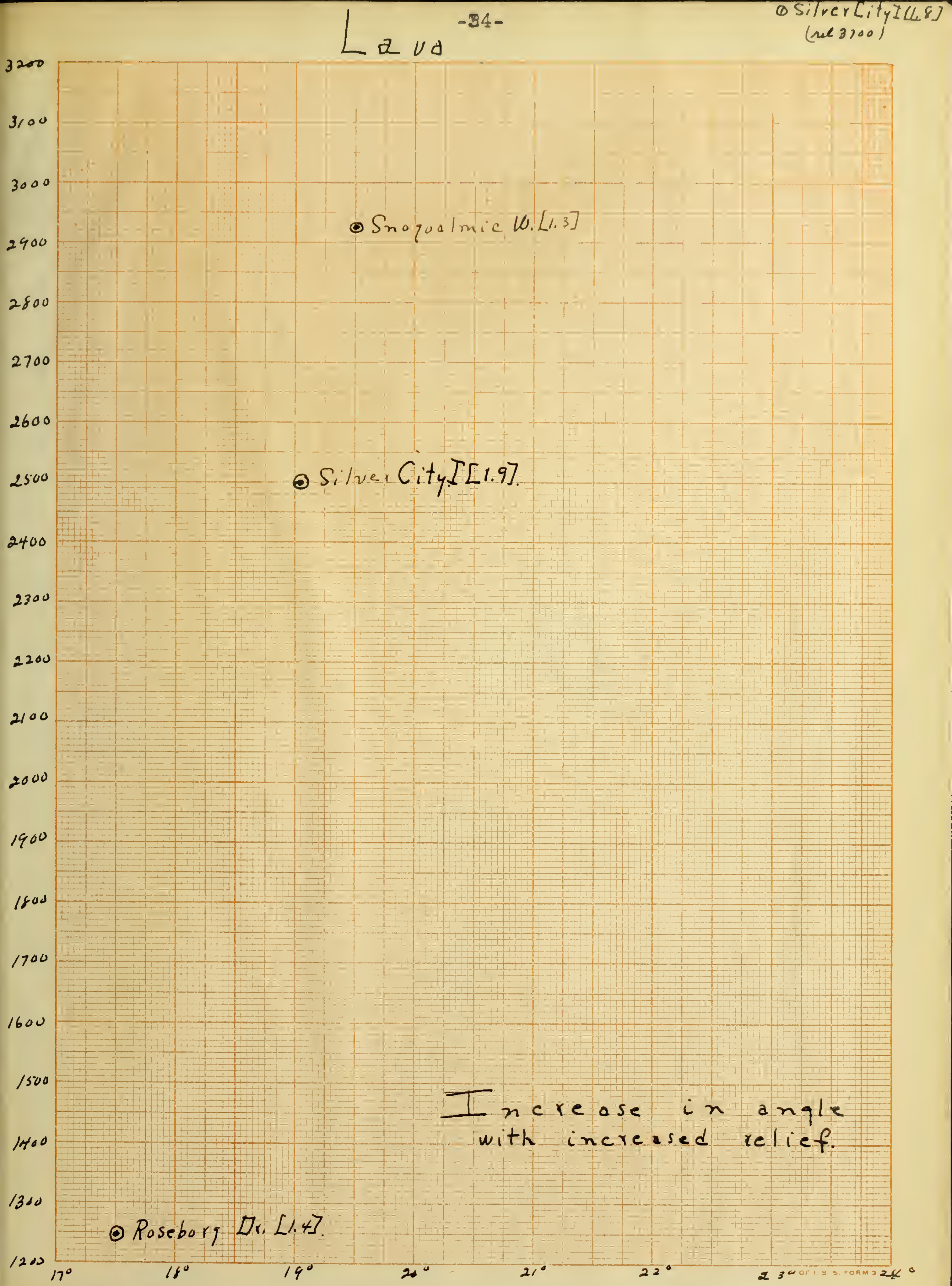


Plate XIX Relief - Angle